INNER BORDERLAND PROVINCE

by Scott D. Drewry and Frank W. Victor

LOCATION

The Inner Borderland province is located offshore southern California from the Anacapa ridge and the Malibu Coast-Santa Monica fault (on the north) to the U.S.-Mexico maritime boundary (on the south) (fig. 93). This assessment province is bounded on the west by the Santa Cruz-Catalina ridge and the Thirtymile bank; to the east, by the Palos Verdes fault zone, and to the southeast by the southern and eastern boundary of the Oceanside-Capistrano basin.

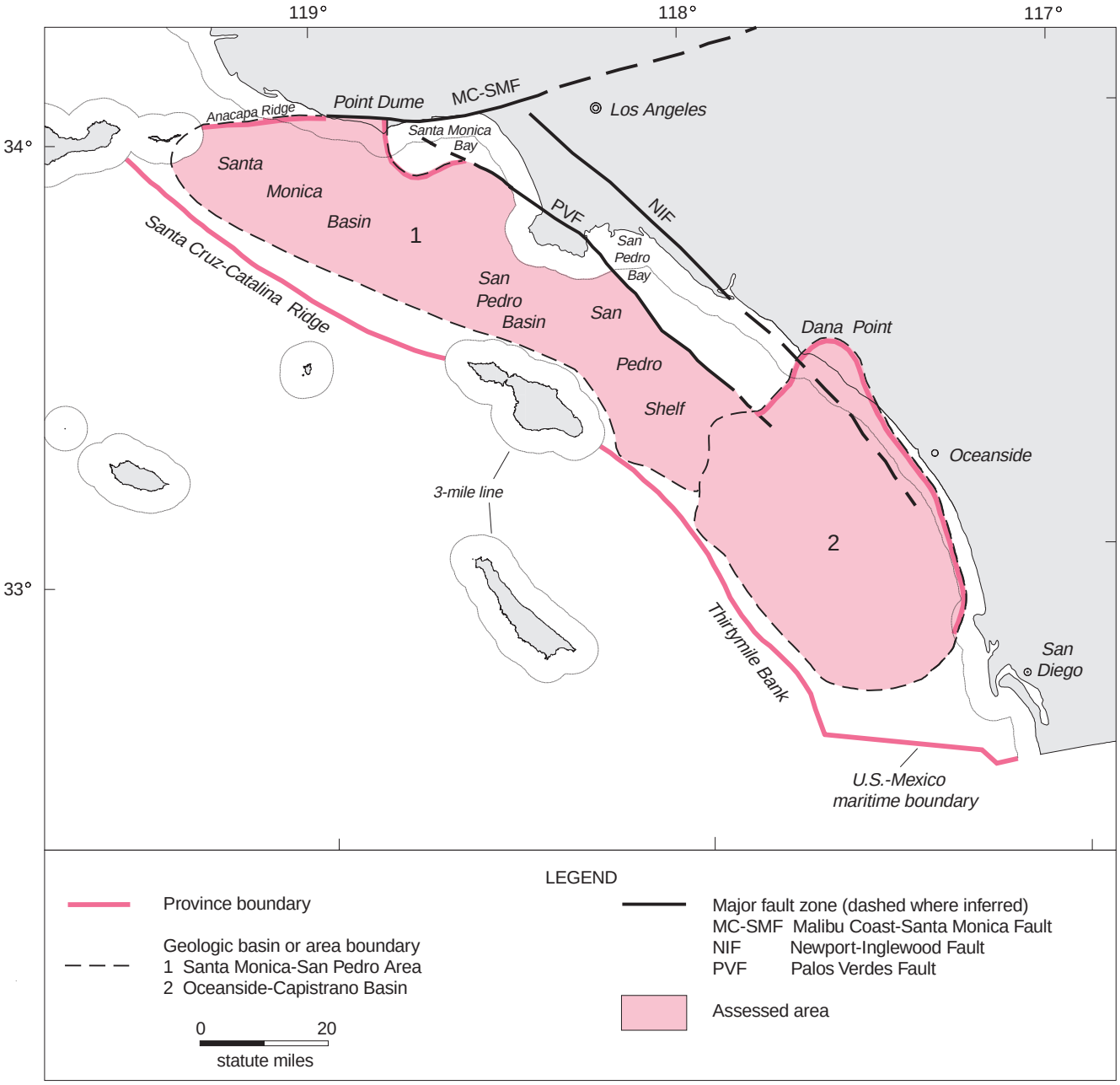

Figure 93. *Map of the Inner Borderland province showing geologic basins and areas, and assessed areas.*

The province encompasses four depositional subareas: Santa Monica basin, San Pedro basin, San Pedro shelf, and the Oceanside-Capistrano basin. The Santa Monica basin, San Pedro basin, and San Pedro shelf have been combined as a single assessment area due to the nearly continuous extent of Neogene strata. The Oceanside-Capistrano basin is depositionally distinct from the Santa Monica-San Pedro assessment area. These assessment areas and the plays defined within them are described in the following summaries.

The Inner Borderland province and its constituent assessment areas differ from other provinces and assessment areas in the Pacific OCS Region in that they include State offshore and onshore areas that are adjacent to the Federal offshore area (fig. 93); other provinces and assessment areas in the Region comprise only Federal offshore areas. The State offshore and onshore areas of the Inner Borderland province were included in this study to facilitate their assessment, which was based in part on information from the Federal offshore area[13].

GEOLOGIC SETTING

The general structure of the province is the result of early Miocene extension and late Pliocene compression. The extension was due to rifting and clockwise rotation of the western Transverse Ranges crustal block (Crouch and Suppe, 1993). In the late Pliocene, a change in microplate geometry resulted

[13] By agreement between the MMS and USGS, the State offshore and onshore areas of the Inner Borderland province were assessed by the MMS rather than the USGS.

Table 29. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Inner Borderland province as of January 1, 1995, by assessment area. All estimates are risked values. The low, mean, and high estimates correspond to the 95th-percentile, mean, and 5th-percentile values of a probability distribution, respectively. Percentile values are not additive; some total mean values may not equal the sum of the component values due to independent rounding.*

Assessment Area	Oil (Bbbl)			Gas (Tcf)			BOE (Bbbl)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Santa Monica-San Pedro Area[1]	0.23	0.68	1.47	0.25	0.77	1.68	0.28	0.82	1.76
Oceanside-Capistrano Basin[1]	0	1.11	2.21	0	1.30	3.17	0	1.34	2.70
Total Province[1]	*0.87*	*1.79*	*3.18*	*0.79*	*2.07*	*4.19*	*1.04*	*2.16*	*3.85*

[1] Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

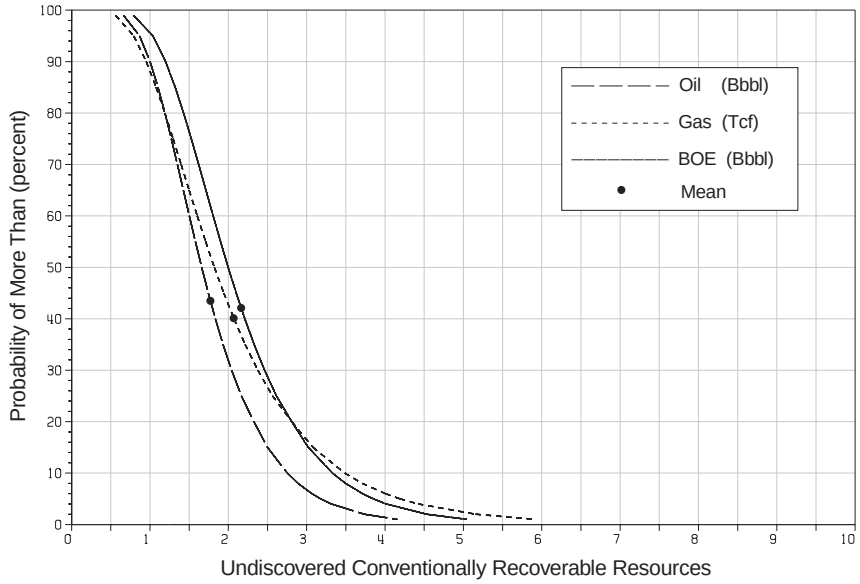

Figure 94. *Cumulative probability plot of estimated undiscovered conventionally recoverable resources of the Inner Borderland province.*

in a change to northwest-trending, right-lateral wrenching with a component of northeast-oriented compression. This history has resulted in a combination of extensional and compressional features.

The Palos Verdes and Newport-Inglewood fault zones dominate the structural style of the eastern part of the province. The Newport-Inglewood fault zone is a wrench zone along which several giant oil fields exist onshore and in State waters. A number of medium- to large-scale compressional structures in the Oceanside-Capistrano basin are associated with the fault zone.

Cretaceous and Neogene strata are present throughout the province. Some Paleogene strata exist in the eastern one-third of the Oceanside-Capistrano basin; however, they are missing in much of the province due to the early Miocene rifting.

EXPLORATION AND DISCOVERY STATUS

Two small fields have been discovered in the onshore portion of the Oceanside-Capistrano Basin assessment area and some petroleum shows have been noted in the Santa Monica-San Pedro assessment area. Offshore exploratory drilling has been restricted due to limited oil and gas leasing opportunities in State and Federal waters.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of the total volume of undiscovered conventionally recoverable resources in the province have been developed by statistically aggregating the constituent assessment area estimates. Estimates of the volume of resources in the Federal offshore, State offshore, and onshore portions of the province were subsequently calculated by summing the estimated volume of resources in the respective portions of the constituent assessment areas.

As a result of this assessment, the total volume of undiscovered conventionally recoverable resources in the Inner Borderland province is estimated to be 1.79 Bbbl of oil and 2.07 Tcf of associated gas (mean estimates). The low, mean, and high estimates of resources in the province are listed in table 29 and illustrated in figure 94.

The Federal offshore portion of the province is expected to contain the majority of these resources, or approximately 1.71 Bbbl of oil and 1.97 Tcf of associated gas (table 30). The State offshore portion of the province is estimated to contain approximately 84 MMbbl of oil and 102 Bcf of associated gas. A negligible volume of resources is expected to exist in the onshore portion of the province.

Table 30. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Inner Borderland province as of January 1, 1995, by area. All estimates are risked mean values. Some total values may not equal the sum of the component values due to independent rounding.*

Area	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
Onshore		negligible	
State Offshore	0.08	0.10	0.19
Federal Offshore	1.71	1.97	2.06
Total	*1.79*	*2.07*	*2.16*

Undiscovered Economically Recoverable Resources

Estimates of the total volume of undiscovered conventionally recoverable resources in the province that may be economically recoverable under various economic scenarios have been developed by statistically aggregating the constituent assessment area estimates.

As a result of this assessment, 1.19 Bbbl of oil and 1.37 Tcf of associated gas are estimated to be economically recoverable from the Inner Borderland province under economic conditions existing as of this assessment (i.e., the $18-per-barrel economic scenario) (table 31). Larger volumes of resources are expected to be economically recoverable under increasingly favorable economic conditions (fig. 95).

The majority of undiscovered economically recoverable resources in the province are expected to exist in the Federal offshore portion of the province.

Total Resource Endowment

As of this assessment, cumulative production from the province was 4.6 Mbbl of oil and 11 MMcf of gas; remaining reserves were estimated to be negligible. These discovered resources (all of which are from the onshore portion of the Oceanside-Capistrano basin) and the aforementioned undiscovered conventionally recoverable resources collectively compose the province's estimated total resource endowment of 1.79 Bbbl of oil and 2.07 Tcf of gas (table 32).

Table 31. *Estimates of undiscovered economically recoverable oil and gas resources in the Inner Borderland province as of January 1, 1995 for three economic scenarios, by assessment area. All estimates are risked mean values. The $18-per-barrel scenario is based on prices of $18 per bbl of oil and $2.11 per Mcf of gas; the $25-per-barrel scenario is based on prices of $25 per bbl of oil and $2.94 per Mcf of gas; the $50-per-barrel scenario is based on prices of $50 per barrel of oil and $5.87 per Mcf of gas. Some total values may not equal the sum of the component values due to independent rounding.*

Assessment Area	$18-per-barrel Scenario			$25-per-barrel Scenario			$50-per-barrel Scenario		
	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
Santa Monica-San Pedro Area[1]	0.44	0.50	0.53	0.50	0.57	0.60	0.59	0.66	0.71
Oceanside-Capistrano Basin[1]	0.74	0.87	0.90	0.88	1.03	1.07	1.02	1.19	1.23
Total Province[1]	*1.19*	*1.37*	*1.43*	*1.39*	*1.60*	*1.67*	*1.61*	*1.85*	*1.94*

[1] Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

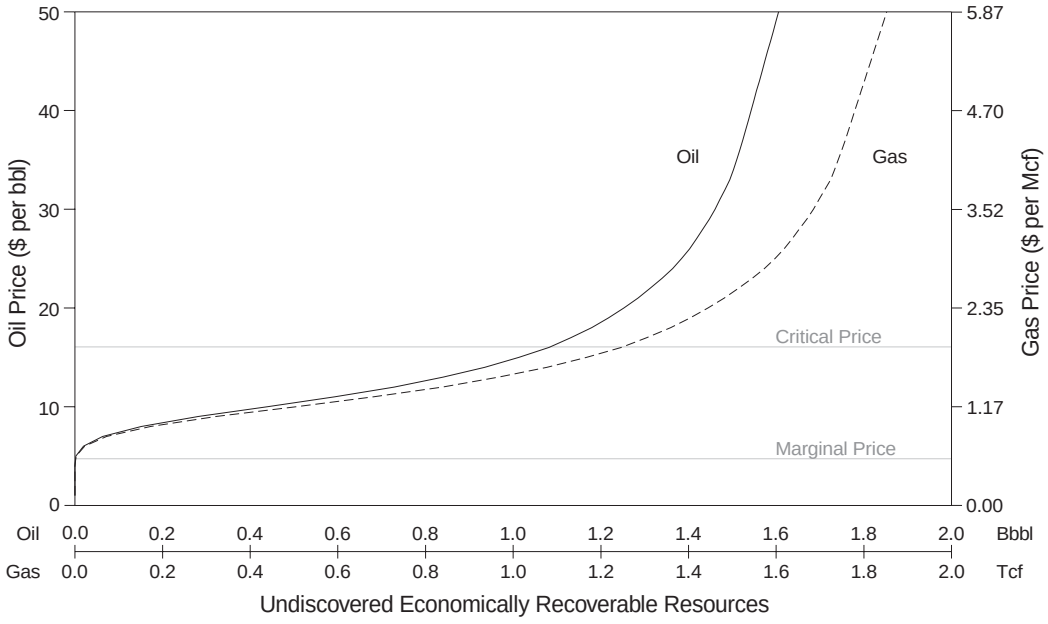

Figure 95. *Price-supply plot of estimated undiscovered economically recoverable resources of the Inner Borderland province.*

Table 32. *Estimates of the total endowment of oil and gas resources in the Inner Borderland province, by assessment area. Estimates of discovered resources (including cumulative production and remaining reserves) and undiscovered resources are as of January 1, 1995. Estimates of undiscovered conventionally recoverable resources are risked mean values. Some total values may not equal the sum of the component values due to independent rounding.*

Assessment Area	Discovered Resources (Reserves)						Undiscovered Conventionally Recoverable Resources			Total Resource Endowment		
	Cumulative Production			Remaining Reserves								
	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
Santa Monica-San Pedro Area[1]	0	0	0	0	0	0	0.68	0.77	0.82	0.68	0.77	0.82
Oceanside-Capistrano Basin[1]	<0.01	<0.01	<0.01	negligible			1.11	1.30	1.34	1.11	1.30	1.34
Total Province[1]	*<0.01*	*<0.01*	*<0.01*	*negligible*			*1.79*	*2.07*	*2.16*	*1.79*	*2.07*	*2.16*

[1] Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

SANTA MONICA-SAN PEDRO AREA

by Scott D. Drewry

LOCATION

The Santa Monica-San Pedro assessment area occupies the northern portion of the Inner Borderland province (fig. 93). The assessment area extends from the Anacapa ridge (on the north) to the Dana Point sill (on the south); it is bounded on the west by the Santa Cruz-Catalina ridge and on the east by the Palos Verdes fault zone (fig. 96). It encompasses three depositional subareas: Santa Monica basin, San

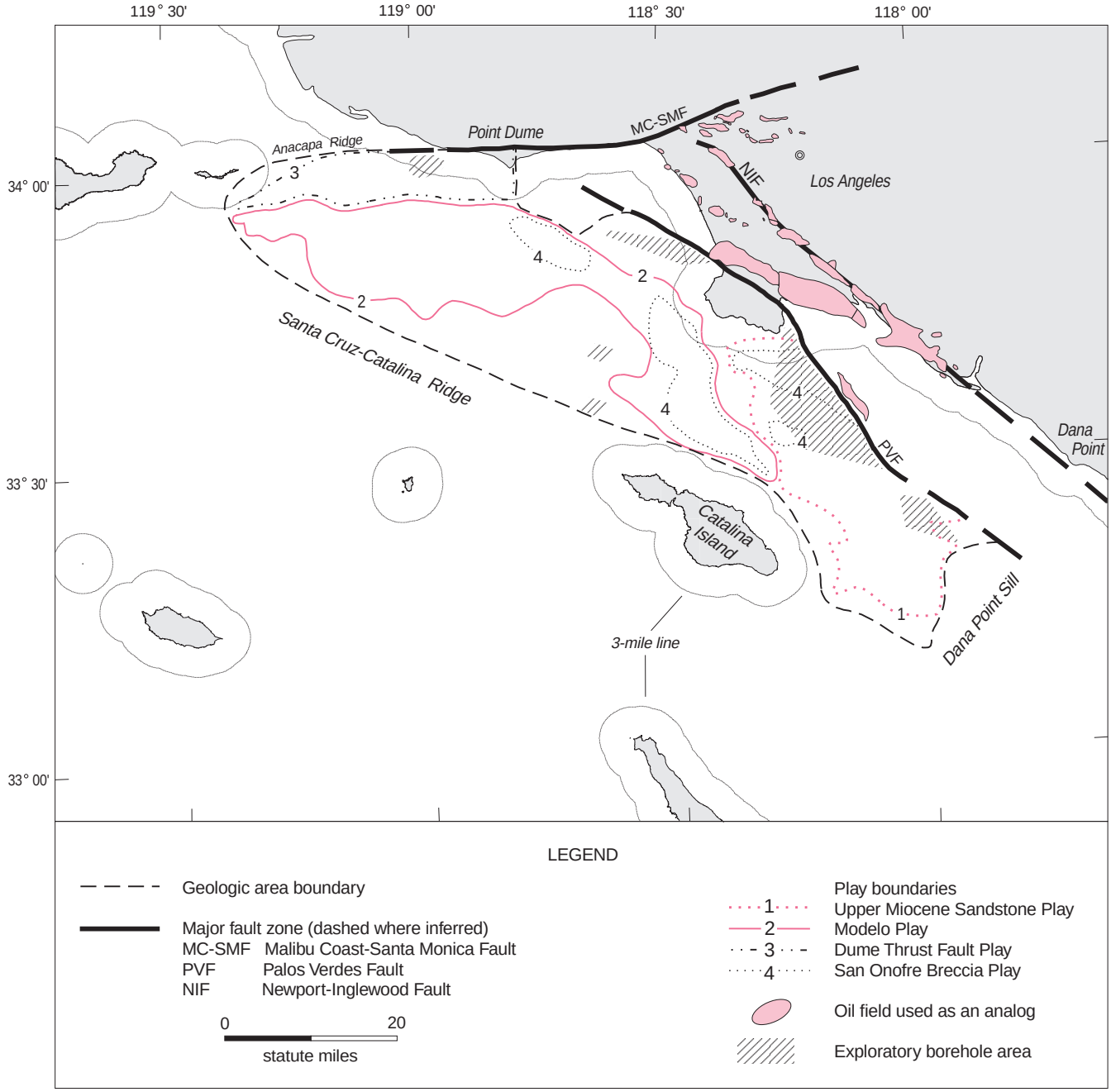

Figure 96. *Map of the Santa Monica-San Pedro assessment area showing petroleum geologic plays, select adjacent fields, and borehole areas.*

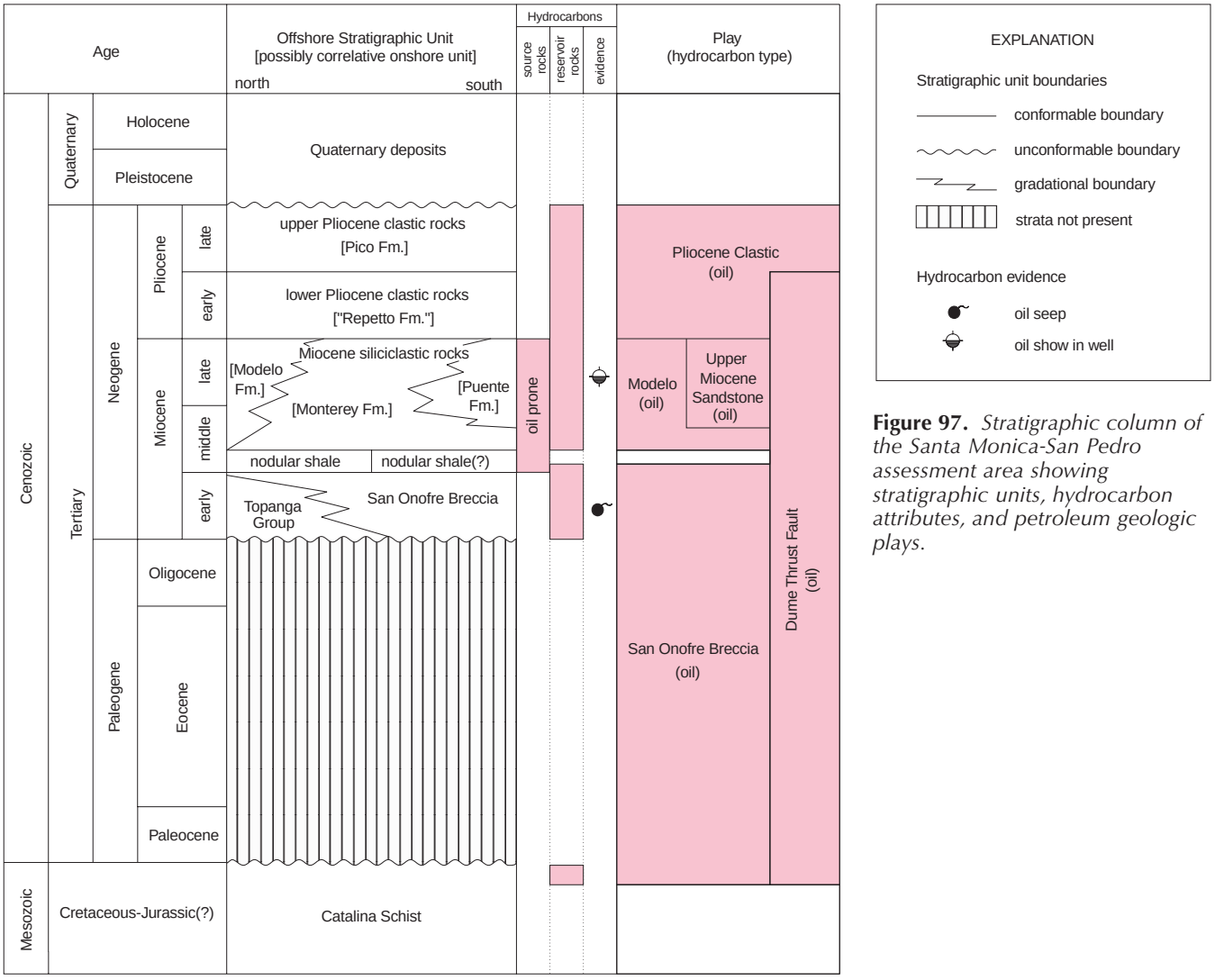

Figure 97. *Stratigraphic column of the Santa Monica-San Pedro assessment area showing stratigraphic units, hydrocarbon attributes, and petroleum geologic plays.*

Pedro basin, and San Pedro shelf. This elongate, northwest-trending assessment area is about 90 miles long and 12 to 40 miles wide and covers an area of about 1,300 square miles. Water depth in the area is as great as 2,000 feet on the San Pedro shelf and 3,000 feet in the Santa Monica and San Pedro basins.

Although the majority of the assessment area is in the Federal offshore area (which is the focus of this study), it includes some adjacent State offshore and onshore areas (fig. 96). These adjacent areas were included in this study to facilitate their assessment, which was based in part on information from the Federal offshore area.

GEOLOGIC SETTING

This geologic area is the seaward extension of the triangular Los Angeles rift basin, which formed by the clockwise rotation of the western Transverse Ranges crustal block. Early Miocene rifting of this block resulted in relatively high heat flow and local isostatic uplift of basement blocks of the Catalina Schist.

Paleogene strata are missing in the area due to the early Miocene rifting. The Neogene stratigraphic section consists primarily of lower Miocene volcanics, local schist-basement debris, middle to upper Miocene organic shales and cherts, and interbedded upper Miocene to lower Pliocene fine-grained clastic rocks (distal facies of the Puente and Tarzana fans of the Los Angeles basin) (fig. 97). These clastic strata are volumetrically concentrated on the eastern and northern perimeters of the assessment area. Upper Pliocene to Holocene fine-grained clastic rocks cover most of the area but are not of sufficient thickness to have appreciable petroleum potential.

EXPLORATION

More than 40 exploratory boreholes (of widely varying depths) have been drilled in several offshore areas (fig. 96); however, no significant accumulations of hydrocarbons have been discovered. Nearly all of the boreholes are located on the periphery of the area; none are located in the central parts of the Santa Monica or San Pedro basins (fig. 96). Most of the boreholes are clustered along the eastern edge of the San Pedro shelf leaving much of the area undrilled. Most of the offshore area, with the exception of the structurally complex nearshore area west of Point Dume, is traversed by a dense grid of seismic-reflection profiles. Offshore exploratory drilling has been restricted due to limited oil and gas leasing opportunities in State and Federal waters.

PLAYS

Five petroleum geologic plays were defined in the assessment area (fig. 97). Three plays were defined on the basis of reservoir rock stratigraphy; these include Cretaceous schist and overlying Miocene clastic reservoirs (San Onofre Breccia play), middle to upper Miocene clastic and chert reservoirs (Modelo play), and middle to upper Miocene clastic reservoirs (Upper Miocene Sandstone play). The Dume Thrust Fault play was defined on the basis of the structural nature of traps along the Malibu Coast fault and the Dume thrust fault. Additionally, a conceptual play of Pliocene clastic reservoirs (Pliocene Clastic play) was defined but not formally assessed.

All of the assessed plays in the Santa Monica-San Pedro assessment area extend into State waters and one of these (Dume Thrust Fault play) extends onshore. Three plays (Upper Miocene Sandstone, Modelo, and San Onofre Breccia plays) are presumed to contain a negligible volume of oil and gas resources in the State offshore area, and only the Federal offshore portion of these plays has been assessed. However, the entire (Federal offshore, State offshore, and onshore) Dume Thrust Fault play has been assessed.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Play-specific estimates of undiscovered conventionally recoverable resources have been developed using the subjective assessment method with adjusted on-shore fields as analogs, and these estimates have been statistically aggregated to estimate the total volume of resources in the assessment area. Select data used to develop the resource estimates are shown in appendix C. Estimates of the volume of resources in the Federal offshore, State offshore, and onshore portions of the Dume Thrust Fault play were subsequently calculated using a subjective area-proportionality factor, and the area-specific play estimates have been summed to estimate the total volume of resources in the respective portions of the assessment area.

As a result of this assessment, the total volume of undiscovered conventionally recoverable resources in the Santa Monica-San Pedro assessment area is estimated to be 683 MMbbl of oil and 769 Bcf of associated gas (mean estimates). This volume may exist in 37 fields with sizes ranging from approximately 95 Mbbl to 320 MMbbl of combined oil-equivalent resources (fig. 98). The majority of these

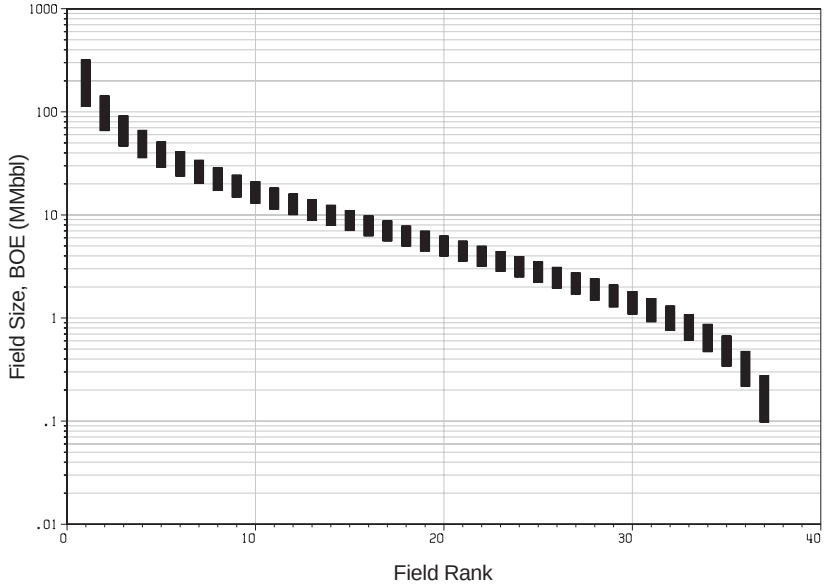

Figure 98. *Field-size rank plot of estimated undiscovered conventionally recoverable resources of the Santa Monica-San Pedro assessment area. Sizes of undiscovered fields are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile value of a probability distribution, respectively.*

Table 33. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Santa Monica-San Pedro assessment area as of January 1, 1995, by play. All estimates are risked values. The low, mean, and high estimates correspond to the 95th-percentile, mean, and 5th-percentile values of a probability distribution, respectively. Percentile values are not additive; some total mean values may not equal the sum of the component values due to independent rounding.*

Play	Oil (MMbbl)			Gas (Bcf)			BOE (MMbbl)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Pliocene Clastic	not assessed								
Upper Miocene Sandstone	0	39	85	0	16	34	0	42	91
Modelo	0	245	736	0	291	879	0	297	877
Dume Thrust Fault[1]	0	367	853	0	448	1,079	0	446	1,037
San Onofre Breccia	0	32	90	0	14	40	0	35	97
Total Assessment Area[1]	*230*	*683*	*1,472*	*252*	*769*	*1,680*	*278*	*820*	*1,763*

[1] Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

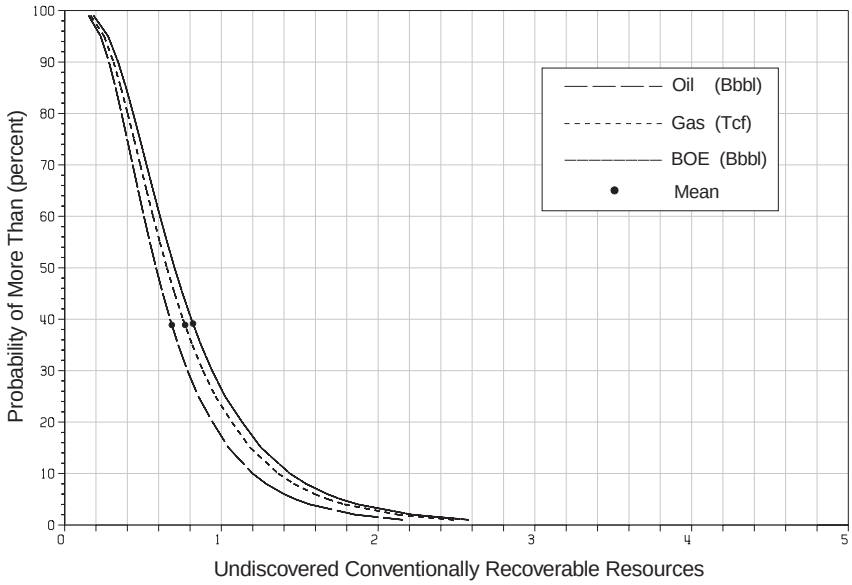

Figure 99. *Cumulative probability plot of estimated undiscovered conventionally recoverable resources of the Santa Monica-San Pedro assessment area.*

resources (approximately 91 percent on a combined oil-equivalence basis) are estimated to exist in the Modelo and Dume Thrust Fault plays. The low, mean, and high estimates of resources in the assessment area are listed in table 33 and illustrated in figure 99.

The Federal offshore portion of the assessment area is expected to contain the majority of these fields and resources, or approximately 646 MMbbl of oil and 724 Bcf of associated gas (table 34). The State offshore portion of the assessment area is estimated to contain approximately 37 MMbbl of oil and 45 Bcf of associated gas. A negligible volume of resources is expected to exist in the onshore portion of the assessment area.

Undiscovered Economically Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the assessment area that may be economically recoverable under various economic scenarios have been developed using the economic assessment method. Select data used to develop the resource estimates are shown in appendix D.

As a result of this assessment, 442 MMbbl of oil and 498 Bcf of associated gas are estimated to be economically recoverable from the Santa Monica-San Pedro assessment area under economic conditions existing as of this assessment (i.e., the $18-per-barrel economic scenario) (table 35). Larger volumes of resources are expected to be economically recoverable under increasingly favorable economic conditions (fig. 100).

Table 34. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Santa Monica-San Pedro assessment area as of January 1, 1995, by area. All estimates are risked mean values. Some total values may not equal the sum of the component values due to independent rounding.*

Area	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
Onshore		negligible	
State Offshore	0.04	0.05	0.05
Federal Offshore	0.65	0.72	0.78
Total Assessment Area	*0.68*	*0.77*	*0.82*

The majority of undiscovered economically recoverable resources in the assessment area are expected to exist in the Federal offshore portion of the area.

Total Resource Endowment

No accumulations of resources have been discovered in the assessment area. Therefore, the aforementioned estimates of undiscovered conventionally recoverable resources compose the estimated total resource endowment of the area.

ACKNOWLEDGMENTS

This assessment of the Santa Monica-San Pedro area was significantly enhanced by the contributions of several persons, including Larry Beyer, Jim Crouch, Thane McCulloh, and Tom Wright. Their experience, patience, and generous cooperation was very helpful. Acknowledgment is also due to Scott Cranswick and Dennis Tayman who performed the seismic interpretative mapping of the area.

ADDITIONAL REFERENCES

Crouch, Bachman, and Associates, Inc., 1989a
Crouch, Bachman, and Associates, Inc., 1989b
Crouch and Suppe, 1993
Vedder, 1987

Table 35. *Estimates of undiscovered economically recoverable oil and gas resources in the Santa Monica-San Pedro assessment area*[1] *as of January 1, 1995, by economic scenario. All estimates are risked mean values. The $18-per-barrel scenario is based on prices of $18 per bbl of oil and $2.11 per Mcf of gas; the $25-per-barrel scenario is based on prices of $25 per bbl of oil and $2.94 per Mcf of gas; the $50-per-barrel scenario is based on prices of $50 per barrel of oil and $5.87 per Mcf of gas.*

Economic Scenario	Oil (MMbbl)	Gas (Bcf)	BOE (MMbbl)
$18 per barrel	442	498	531
$25 per barrel	503	565	603
$50 per barrel	591	664	709

[1] Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

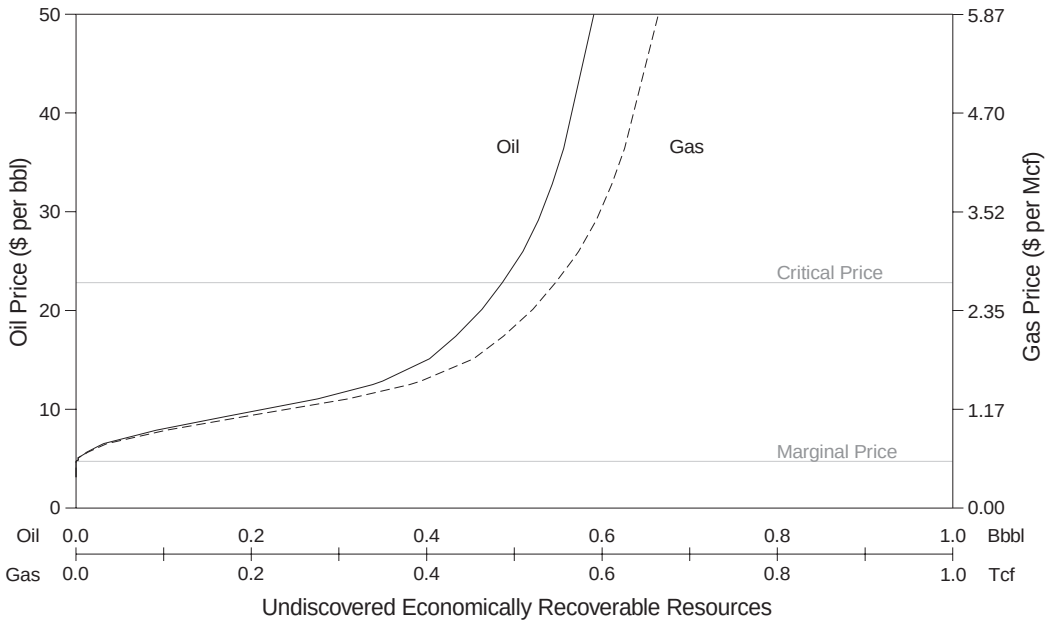

Figure 100. *Price-supply plot of estimated undis-covered economically recoverable resources of the Santa Monica-San Pedro assessment area.*

PLIOCENE CLASTIC PLAY

PLAY DEFINITION

The Pliocene Clastic play of the Santa Monica-San Pedro assessment area is defined to include accumulations of oil and associated gas in Pliocene clastic strata. The area of this conceptual play is estimated to be similar to that of the Modelo play (fig. 96); however, rocks of this play may extend farther west on the Santa Cruz-Catalina ridge.

PETROLEUM GEOLOGIC CHARACTERISTICS

This play is not considered to have an internal (Pliocene) petroleum source. It may, however, be sourced from underlying Miocene strata.

Potential reservoir rocks of this play include Pliocene sandstones, siltstones, and mudstones of the "Repetto"[14] and Pico Formations (fig. 97). However, these strata may be of relatively poor reservoir quality and may lack sufficient seal.

The majority of traps in this play are expected to be large stratigraphic pinchouts against the Santa Cruz-Catalina ridge. Some structural and fault traps may exist in the central and eastern portions of the play.

EXPLORATION

No exploratory wells have been drilled in this play.

RESOURCE ASSESSMENT

This play was not formally assessed due to significant uncertainties regarding source rocks, reservoir rocks, and traps.

UPPER MIOCENE SANDSTONE PLAY

PLAY DEFINITION

The Upper Miocene Sandstone play of the Santa Monica-San Pedro assessment area is defined to include accumulations of oil and associated gas in distal Puente Fan sandstones in fault traps on the San Pedro shelf. This play is fundamentally similar to the Puente Fan Sandstone play of the Los Angeles Basin province; however, there are sufficient differences to warrant the frontier status of this play. These include (1) the presence of finer grained reservoir rocks (deposited in more distal environments), (2) the presence of a thinner section of overburden (i.e., deposition of overlying Pliocene strata was confined by the Palos Verdes paleohigh), and (3) the possible presence of a larger volume of "Monterey" rocks in this play.

This play extends over most of the San Pedro shelf from the Palos Verdes fault west toward Catalina Island and from the Palos Verdes Peninsula south to the Dana Point sill (fig. 96). The Federal offshore portion of the play is approximately 30 miles long and 8 to 10 miles wide and covers an area of approximately 240 square miles. The depth to reservoir rocks in the play ranges from 600 to 5,000 feet and averages 3,000 feet below the seafloor.

PETROLEUM GEOLOGIC CHARACTERISTICS

Petroleum source rocks for this play include the lower middle Miocene "nodular shale" and interbedded middle Miocene pelagic mudstones and shales of the Puente Formation (fig. 97). In the onshore Los Angeles basin, these rocks are rich in marine-derived kerogen; total organic carbon content averages 4 percent and is as high as 10 and 16 percent in the "nodular shale" and Puente Formation, respectively (Jeffrey and others, 1991). High heat flow in the Los Angeles basin has generated oil from these kerogens at depths as shallow as 8,000 feet; the oil typically has moderately low gravity (less than 25 °API) and high sulphur content (greater than 1 percent). However, the relatively thin Neogene section on the San Pedro shelf (average thickness is 3,000 feet and maximum thickness is 7,000 feet) probably precludes significant oil generation in this area; therefore, migration from source rocks outside this play may be required. Long-distance migration from proven areas east of the Palos Verdes fault zone is unlikely due to the presence of a number of fault barriers; this is suggested by the fact that all five exploratory wells drilled in the most prospective areas of this play have been dry. Migration from source rocks in the San Pedro basin is similarly dubious.

[14] The U.S. Geological Survey has abandoned the term "Repetto" (originally used to describe rocks that were deposited during the Repettian Stage) (Keroher and others, 1966); however, the term is widely used by the geological community and is used in this report.

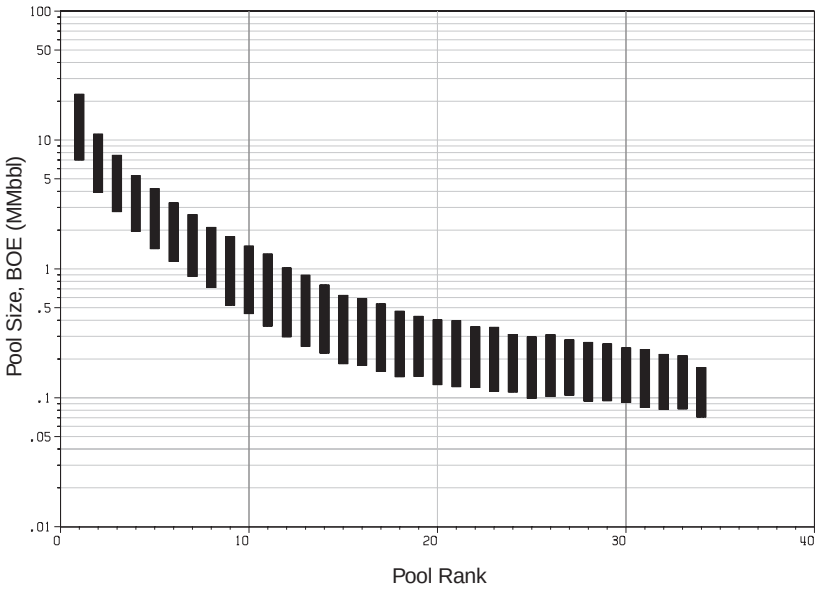

Figure 101. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Upper Miocene Sandstone play, Santa Monica-San Pedro assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

Reservoir rocks of this play are composed of distal Puente Fan sands that have "spilled" over the Palos Verdes paleofault at bathymetric lows south of the Palos Verdes high (north of the Beta field). Although the thickness of the section is less than half of that east of the fault (average thickness of 3,000 feet) and the rocks are undoubtedly finer grained, sufficient reservoir section does exist.

Reservoir parameters for this play were significantly reduced from those of the Puente Fan Sandstone play of the Los Angeles Basin province. As stated above, oil migration into reservoir sandstones of this play is expected to have been limited due to the presence of a dense network of faults that are normal to (and presumably an impediment to) migration paths.

The network of northwest-trending faults that may have impeded Puente Fan sediments and oil migration from the east does provide a wealth of potential fault traps in the play. Many anticlinal and turbidite sandstone channel traps may also exist. Interbedded siltstones, mudstones, and shales may provide seals, and additional sealing may be provided by overlying upper Pliocene siltstones and mudstones.

EXPLORATION

Five offshore exploratory wells, which are clustered along the eastern edge of the San Pedro shelf, have been drilled in this play. No significant accumulations of hydrocarbons have been discovered.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the Federal offshore portion of the play have been developed using the subjective assessment method with adjusted onshore analogs from the Los Angeles basin. Select data used to develop the resource estimates are shown in appendix C.

As a result of this assessment, the Federal offshore portion of the play is estimated to contain 39 MMbbl of oil and 16 Bcf of associated gas (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 34 pools with sizes ranging from approximately 70 Mbbl to 25 MMbbl of combined oil-equivalent resources (fig. 101). The low, mean, and high estimates of resources in the play are listed in table 33.

MODELO PLAY

PLAY DEFINITION

The Modelo play of the Santa Monica-San Pedro assessment area is defined to include accumulations of oil and associated gas in structural and fault traps of the Modelo and Monterey Formations[15]. This conceptual play exists in the Santa Monica and San Pedro basins from the Dume thrust fault south to Catalina Island and from the Palos Verdes high to the Santa Cruz-Catalina ridge (fig. 96). This irregularly shaped play extends for almost 50 miles from its northwest to southeast margins and covers an area of about 350 square miles. Reservoir rock depths in the play range from 0 to 15,000 feet below the seafloor.

[15] Middle to upper Miocene strata of the Modelo and Monterey Formations exist as interfingered facies in the Santa Monica-San Pedro assessment area. The Modelo Formation consists of fine-grained clastic strata that were deposited in distal environments; whereas, the Monterey Formation consists of a combination of fine-grained clastic strata and chert that were deposited predominantly by pelagic rain. Although these middle to upper Miocene strata include a mixture of facies, the predominant facies is presumed to be clastic. Therefore, all middle to upper Miocene strata exclusive of the Puente Formation have been included in the Modelo play, and reservoir rocks in the play are assumed to have characteristics similar to clastic Modelo reservoirs in the onshore Santa Barbara-Ventura basin.

PETROLEUM GEOLOGIC CHARACTERISTICS

Petroleum source rocks for this play include the lower middle Miocene "nodular shale" and interbedded middle to upper Miocene pelagic mudstones and shales of the Monterey Formation (fig. 97). In the onshore Los Angeles basin, these rocks are rich in marine-derived kerogen and have an average total organic carbon content of about 4 percent (Jeffrey and others, 1991; Philippi, 1975). High heat flow in the Los Angeles basin has generated oil from "nodular shale" kerogens at depths as shallow as 8,000 feet; the oil typically has moderately low gravity (less than 25 °API) and high sulphur content (greater than 1 percent). A fairly large "oil kitchen" may exist in the northwest portion of the Santa Monica basin, which has as much as 12,000 feet of Pliocene overburden; a much smaller "kitchen" may exist in the central portion of the San Pedro basin, where 8,000 feet of overburden exists.

Reservoir rocks of this play include middle to upper Miocene clastic strata of the Modelo Formation and fractured shales and cherts of the Monterey Formation (fig. 97); rocks of both of these reservoir types exist in coastal outcrops north of the play. Cherts with minimal clastic contamination may be good fractured reservoirs; however, the location and

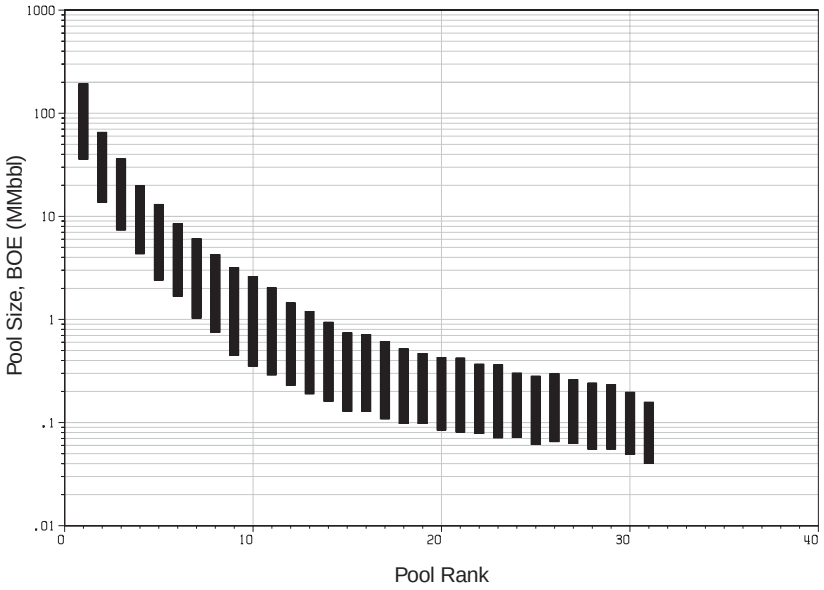

Figure 102. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Modelo play, Santa Monica-San Pedro assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

degree of clastic contamination in the area are unknown. Most of the reservoir potential in the play is assumed to be in fine-grained clastic Modelo rocks, which may have fair to good reservoir quality.

Anticlinal and fault traps are expected in this play, although strata are relatively undeformed compared to other plays in the area. As a result, fewer but potentially larger (area) traps may exist. Interbedded siltstones, mudstones, and shales may provide seals, and additional sealing may be provided by overlying lower Pliocene siltstones and mudstones.

EXPLORATION

No exploratory wells have been drilled in this play.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the Federal offshore portion of the play have been developed using the subjective assessment method with clastic Modelo analogs from the onshore Santa Barbara-Ventura basin (see discussion above). Select data used to develop the resource estimates are shown in appendix C.

As a result of this assessment, the Federal offshore portion of the play is estimated to contain 245 MMbbl of oil and 291 Bcf of associated gas (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 31 pools with sizes ranging from approximately 40 Mbbl to 195 MMbbl of combined oil-equivalent resources (fig. 102). The low, mean, and high estimates of resources in the play are listed in table 33.

DUME THRUST FAULT PLAY

PLAY DEFINITION

The Dume Thrust Fault play of the Santa Monica-San Pedro assessment area is defined to include accumulations of oil and associated gas in fault traps along the Dume thrust fault and the Malibu Coast fault. This frontier play exists onshore and offshore (in Federal and State waters) at the northern margin of the area (fig. 96). The play extends approximately 25 miles westward from Point Dume to the area south of Anacapa ridge and encompasses a total area of about 160 square miles. Reservoir rock depths in the play range from 0 to 15,000 feet below the seafloor.

PETROLEUM GEOLOGIC CHARACTERISTICS

Petroleum source rocks for this play include the lower middle Miocene "nodular shale" and interbedded middle to upper Miocene mudstones and shales of the Monterey Formation (fig. 97). In the onshore Los Angeles basin, these rocks are rich in marine-derived kerogen and have an average total organic carbon content of about 4 percent (Jeffrey and others, 1991; Philippi, 1975). High heat flow in the Los Angeles basin has generated oil from "nodular shale" kerogens at depths as shallow as 8,000 feet; the oil typically has moderately low gravity (less than 25 °API) and high sulphur content (greater than 1 percent). A fairly large "oil kitchen" may exist in the northwest portion of the Santa Monica basin, which has as much as 12,000 feet of Pliocene overburden.

This play has a variety of potential reservoir rocks including Catalina Schist basement; clastic rocks of the Topanga Group, San Onofre Breccia, Modelo Formation, and Repetto Formation; and fractured rocks of the Monterey Formation and "nodular shale" (fig. 97). Monterey strata in this play have been penetrated by one exploratory well and a few coreholes. Repetto strata (which have not been drilled) are predicted to exist based on extrapolation of a presumably equivalent seismic-stratigraphic unit from Santa Monica Bay. Outcrops in the adjacent coastal area further suggest that Topanga, Modelo, and Monterey strata exist in the offshore area; however, seismic data quality in State waters west of Point Dume is poor. The presence of laumontite (which exists in coastal outcrops) may reduce reservoir quality to an unknown degree.

The primary trapping mechanisms in this play are faults of the Dume thrust fault and Malibu Coast fault zones. Subthrust accumulations may also exist. The presence and effectiveness of seals are uncertain. Some seals may be provided by interbedded siltstones, mudstones, and shales.

EXPLORATION

Two exploratory wells have been drilled in the Federal offshore area of this play; tar was observed in the cuttings from one of the wells. Five wells have been drilled in State waters, and visible shows of oil were observed in the cuttings from one of these wells.

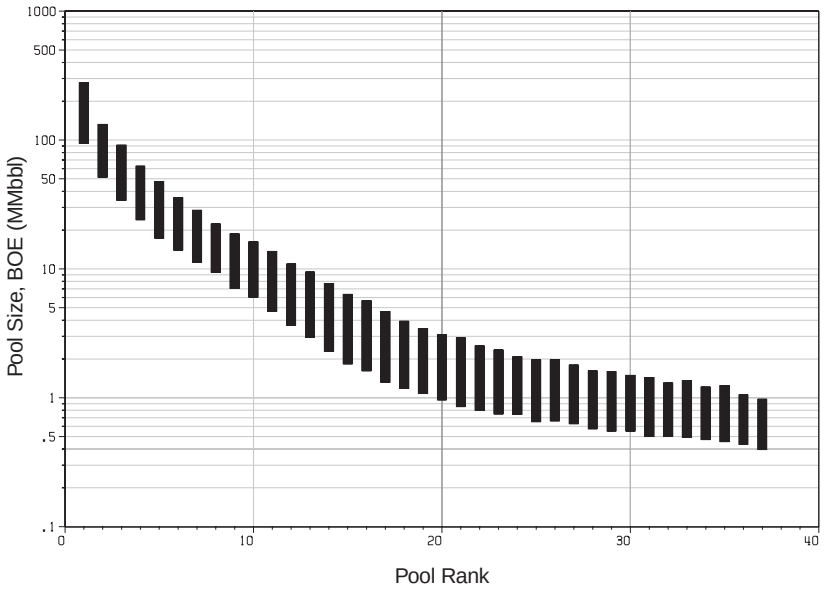

Figure 103. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Dume Thrust Fault play, Santa Monica-San Pedro assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method. Select data used to develop the resource estimates are shown in appendix C.

As a result of this assessment, the play is estimated to contain 367 MMbbl of oil and 448 Bcf of associated gas (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 37 pools with sizes ranging from approximately 395 Mbbl to 280 MMbbl of combined oil-equivalent resources (fig. 103). The low, mean, and high estimates of resources in the play are listed in table 33.

The majority of these pools and resources, or approximately 330 MMbbl of oil and 403 Bcf of associated gas, are expected to exist in the Federal offshore portion of the play. The remaining pools and resources, or approximately 37 MMbbl of oil and 45 Bcf of associated gas, are expected to exist in the State offshore portion of the play. A negligible volume of resources is expected to exist in the onshore portion of the play.

SAN ONOFRE BRECCIA PLAY

PLAY DEFINITION

The San Onofre Breccia play of the Santa Monica-San Pedro assessment area is defined to include accumulations of oil and associated gas in stratigraphic and structural traps of the fractured Catalina Schist, the schist-derived San Onofre Breccia, and overlying "nodular shale." This conceptual play exists in four noncontiguous subareas which cover a total area of approximately 175 square miles (fig. 96). Depth to the reservoir section ranges from 2,000 to 9,000 feet below the seafloor.

Catalina Schist of the Palos Verdes paleohigh was the primary sediment source for reservoir rocks of this play, which were deposited within a "sediment halo" adjacent to the high. This "halo" has been subsequently dissected by erosion (e.g., Redondo Canyon), resulting in four noncontiguous subareas of reservoir rock. An extensive body of potentially analogous debris-fan strata along the east margin of the Santa Cruz-Catalina ridge has not been included in this play due to the unknown lithologic character (schist debris or volcaniclastics) of the strata.

Reservoir rocks equivalent to those included in this play extend eastward and have been assessed

as the San Onofre Breccia play of the Los Angeles Basin province (see this report). Similarly, equivalent rocks are presumed to extend farther eastward into the State offshore and onshore portions of the Los Angeles basin where they have been assessed as part of the Southwestern Shelf play by the U.S. Geological Survey (Beyer, 1995).

PETROLEUM GEOLOGIC CHARACTERISTICS

The petroleum source rock for this play is the lower middle Miocene "nodular shale" (fig. 97). In the onshore Los Angeles basin, this unit is rich in marine-derived kerogen and has an average total organic carbon content of 3 to 4 percent (Jeffrey and others, 1991). High heat flow in the Los Angeles basin has generated oil from these kerogens at depths as shallow as 8,000 feet; the oil typically has moderately low gravity (less than 25 °API) and high sulphur content (greater than 1 percent). Oil gravity often increases with depth; this underscores the importance of identifying traps with possible migration pathways to deeper generative centers onshore (a limited migration distance).

The primary reservoir rocks for this play are lower Miocene sandstones and breccias of the San Onofre Breccia (Catalina Schist eroded from the Palos Verdes paleohigh) and locally fractured Cretaceous (and possibly Jurassic) rocks of the Catalina Schist. The lowermost, possibly fractured, portion of the "nodular shale" may contain potential reservoir rocks and is also included in this play (fig. 97). Reservoir quality may be variable; porosities of analogous reservoirs in the onshore Los Angeles basin range from 12 to 31 percent.

Faults and pinchouts against local basement irregularities may produce many traps in the area; however, only traps located within the "sediment halo" of the Palos Verdes paleohigh are considered viable targets in this play. The overlying "nodular shale" may provide a seal (as well as a petroleum source and reservoir rock) for the traps. The traps are expected to be small; productive areas of analog fields in the onshore Los Angeles basin range from 15 to 600 acres.

EXPLORATION

Four offshore exploratory wells have been drilled in this play. Tar was observed in the sidewall cores from one of the wells. Offshore oil seeps south of the Palos Verdes Peninsula are of unknown affinity but are likely leaking from the San Onofre Breccia where the strata offlap the Palos Verdes high.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the Federal offshore portion of the play have been developed using the subjective assessment method with adjusted analogs from the onshore Los Angeles basin (e.g., El Segundo, Playa Del Rey, and Venice Beach fields). Select data used to develop the resource estimates are shown in appendix C.

As a result of this assessment, the Federal offshore portion of the play is estimated to contain 32 MMbbl of oil and 14 Bcf of associated gas (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 14 pools with sizes ranging from approximately 300 Mbbl to 30 MMbbl of combined oil-equivalent resources (fig. 104). The low, mean, and high estimates of resources in the play are listed in table 33.

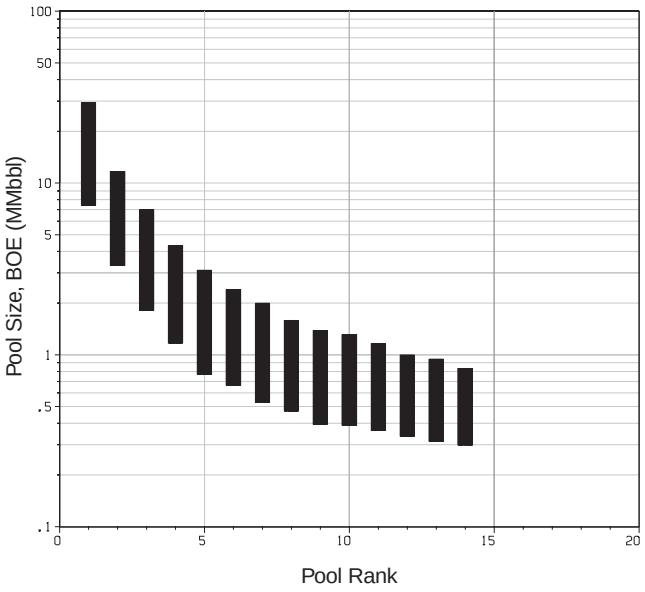

Figure 104. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the San Onofre Breccia play, Santa Monica-San Pedro assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

OCEANSIDE-CAPISTRANO BASIN

by Frank W. Victor

LOCATION

The Oceanside-Capistrano Basin assessment area is the southernmost area in the Inner Borderland province (fig. 93). Most of the basin is located offshore; however, a small, partly exhumed portion of the basin exists onshore near Dana Point (fig. 105). This onshore area of the basin is referred to as the Capistrano syncline; it is bounded on the north by the Coast Ranges and extends about 10 miles in width from the San Joaquin Hills eastward to a generally north-south-trending boundary along which Cretaceous strata are exposed in outcrop. Offshore, the basin is bounded on the northwest by the Dana Point sill and extends southerly about 50 miles to the vicinity of La Jolla; it is bounded to the west by the Thirtymile bank and extends about 30 miles east into State waters. The entire basin is about 50 miles long and averages 30 miles in width and occupies an area of about 1,500 square miles. Water depth in the basin ranges from 0 (coastline) to about 3,000 feet.

Although the majority of the assessment area is in the Federal offshore area (which is the focus of this study), it includes some adjacent State offshore and onshore areas (fig. 105). These adjacent areas were included in this study to facilitate their assessment, which was based in part on information from the Federal offshore area.

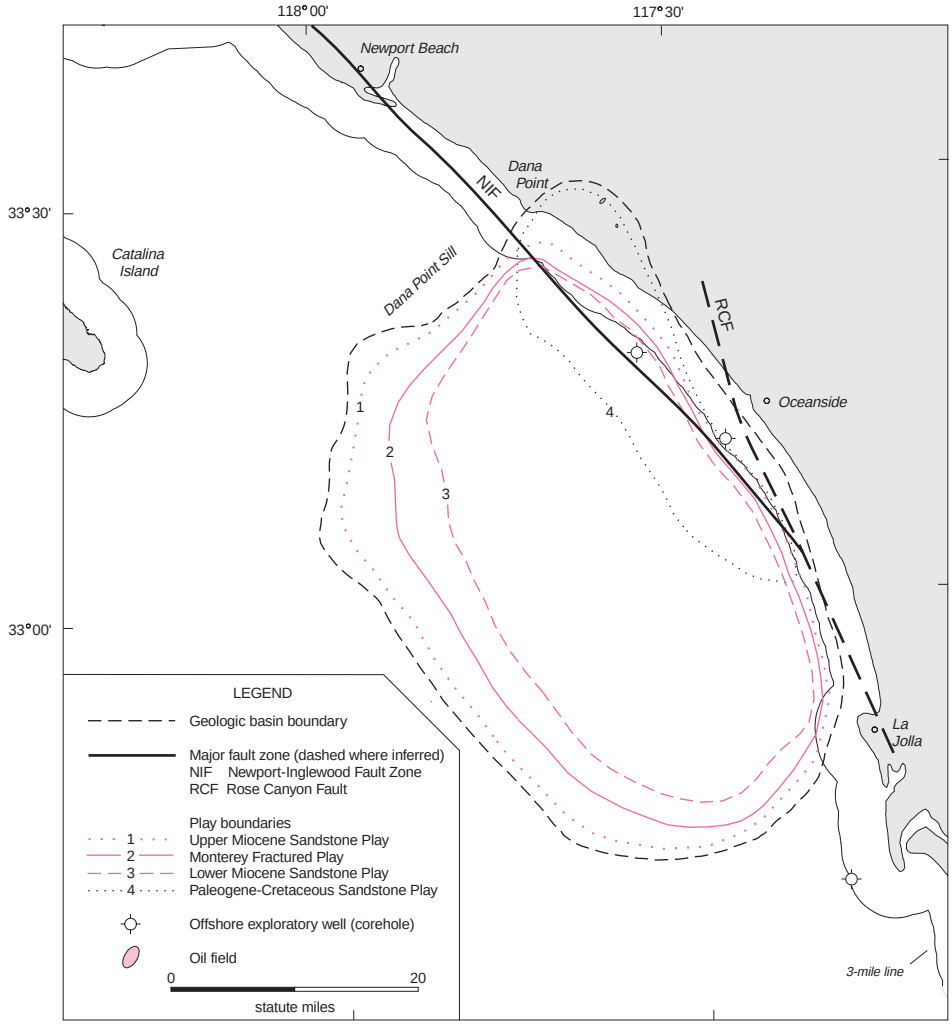

Figure 105. *Map of the Oceanside-Capistrano Basin assessment area showing petroleum geologic plays, offshore wells, and fields.*

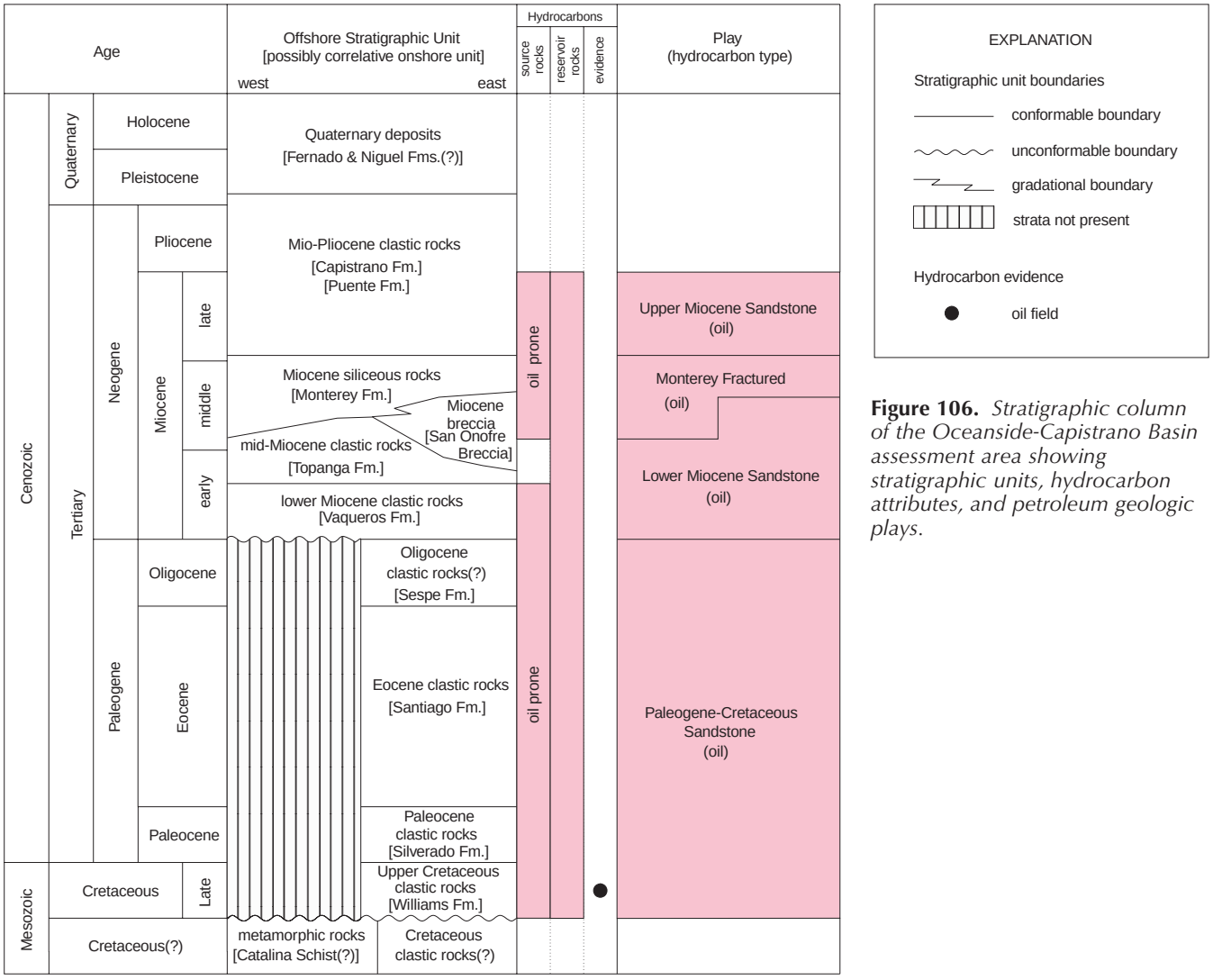

Figure 106. *Stratigraphic column of the Oceanside-Capistrano Basin assessment area showing stratigraphic units, hydrocarbon attributes, and petroleum geologic plays.*

GEOLOGIC SETTING

The Oceanside-Capistrano basin is an asymmetrical structural trough filled with up to 11,000 feet of Cretaceous and Tertiary marine and nonmarine rocks (fig. 106). The northwest-trending Newport-Inglewood fault zone lies offshore near the eastern margin of the basin (fig. 105); the fault has been a major feature in the tectonic and structural evolution of the basin. Large, compressional, fault-bounded anticlines, faulted homoclines, and stratigraphic pinchouts west of the fault zone are evident on seismic-reflection profiles. Most of these structures are located in the Federal offshore area, but a few extend into the State offshore area; these structures are numerous and large enough to contain significant quantities of oil and gas. The Newport-Inglewood structural trend has major petroleum significance in the Oceanside-Capistrano basin since this is the same fault and structural trend along which several prolific oil fields exist in the onshore Los Angeles basin.

The Capistrano syncline is a flat-bottomed, north-south-trending structural trough formed by downwarping of the eastern part of the San Joaquin Hills on the west and down-to-the-west displacement of the Cristianitos fault zone on the east. The syncline is separated from the Los Angeles basin proper by the structurally high San Joaquin Hills and its northward extension into the subsurface. Up to 3,700 feet of middle and upper Miocene marine rocks overlie schist breccia and Paleogene and Cretaceous strata within the syncline (Wright, 1991).

EXPLORATION

Exploration within the offshore part of the basin has been limited. Only two boreholes (the Mobil San Clemente #1 and Shell Oceanside #1 coreholes) have

been drilled offshore. The coreholes were drilled as stratigraphic tests in the 1960's and did not encounter any oil or gas. The Mobil San Clemente corehole penetrated Pliocene and Miocene rocks (presumably of the Capistrano and Monterey Formations, and the San Onofre Breccia). The Shell Oceanside corehole penetrated Pliocene rocks (presumably of the Capistrano Formation). No deep exploratory wells have been drilled in the basin.

A number of high-quality seismic-reflection surveys have been recorded offshore. Many of the profiles from these surveys extend into State waters.

Onshore, more than 60 exploratory wells have been drilled from the early 1950's to 1984. Two fields—the San Clemente and Cristianitos Creek fields—have been discovered. Collectively, these fields produced a very small quantity (less than 5 Mbbl) of high-gravity (45 to 54 °API) oil from the Upper Cretaceous Williams Formation in the late 1950's. Both fields were considered to be subcommercial and have been abandoned. One of the last wells was drilled in 1981 as an extension to the San Clemente field, and it was dry.

PLAYS

Four petroleum geologic plays within the basin have been defined; the plays are defined on the basis of reservoir rock stratigraphy (fig. 106). The plays (and corresponding reservoir rock formations) are (1) the Upper Miocene Sandstone play (Capistrano Formation), (2) the Monterey Fractured play (Monterey Formation), (3) the Lower Miocene Sandstone play (San Onofre Breccia and Topanga and Vaqueros Formations), and (4) the Paleogene-Cretaceous Sandstone play (Williams, Silverado, Santiago, and Sespe(?) Formations).

The Upper Miocene Sandstone, Monterey Fractured, and Lower Miocene Sandstone plays are restricted to the offshore area of the basin; these plays are considered to be conceptual plays based on the absence of directly detected hydrocarbons. The Paleogene-Cretaceous Sandstone play exists onshore and offshore and is an established play because hydrocarbon accumulations have been discovered in the play onshore.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Play-specific estimates of undiscovered conventionally recoverable resources have been developed using the subjective assessment method, and these estimates have been statistically aggregated to estimate the total volume of resources in the assessment area. Select data used to develop the resource estimates are shown in appendix C. Estimates of the volume of resources in the Federal offshore, State offshore, and onshore portions of each play were subsequently calculated using a subjective area-proportionality factor, and the area-specific play estimates have been summed to estimate the total volume of resources in the respective portions of the assessment area.

As a result of this assessment, the total volume of undiscovered conventionally recoverable resources in the Oceanside-Capistrano Basin assessment area is estimated to be 1.11 Bbbl of oil and 1.30 Tcf of associated gas (mean estimates). This volume may exist in 51 fields with sizes ranging from approximately 95 Mbbl to 450 MMbbl of combined oil-

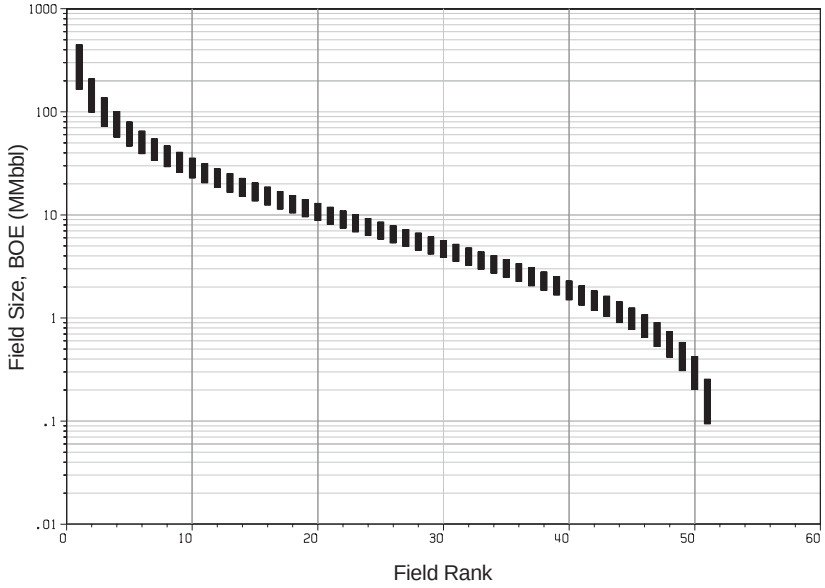

Figure 107. *Field-size rank plot of estimated undiscovered conventionally recoverable resources of the Oceanside-Capistrano Basin assessment area. Sizes of undiscovered fields are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile value of a probability distribution, respectively.*

equivalent resources (fig. 107). The low, mean, and high estimates of resources in the assessment area are listed in table 36 and illustrated in figure 108.

The Federal offshore portion of the assessment area is expected to contain the majority of these fields and resources, or approximately 1.07 Bbbl of oil and 1.25 Tcf of associated gas (table 37). The State offshore portion of the assessment area is estimated to contain approximately 47 MMbbl of oil and 57 Bcf of associated gas. A negligible volume of resources is expected to exist in the onshore portion of the assessment area.

Table 36. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Oceanside-Capistrano Basin assessment area as of January 1, 1995, by play. All estimates are risked values. The low, mean, and high estimates correspond to the 95th-percentile, mean, and 5th-percentile values of a probability distribution, respectively. Percentile values are not additive; some total mean values may not equal the sum of the component values due to independent rounding.*

Play	Oil (MMbbl)			Gas (Bcf)			BOE (MMbbl)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Upper Miocene Sandstone[1]	0	514	1,191	0	274	648	0	563	1,304
Monterey Fractured[1]	0	387	768	0	452	983	0	467	935
Lower Miocene Sandstone[1]	0	208	711	0	568	2,466	0	309	1,116
Paleogene-Cretaceous Sandstone[1]	0	3	14	0	8	39	0	4	21
Total Assessment Area[1]	*0*	*1,112*	*2,211*	*0*	*1,302*	*3,174*	*0*	*1,343*	*2,698*

[1] Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

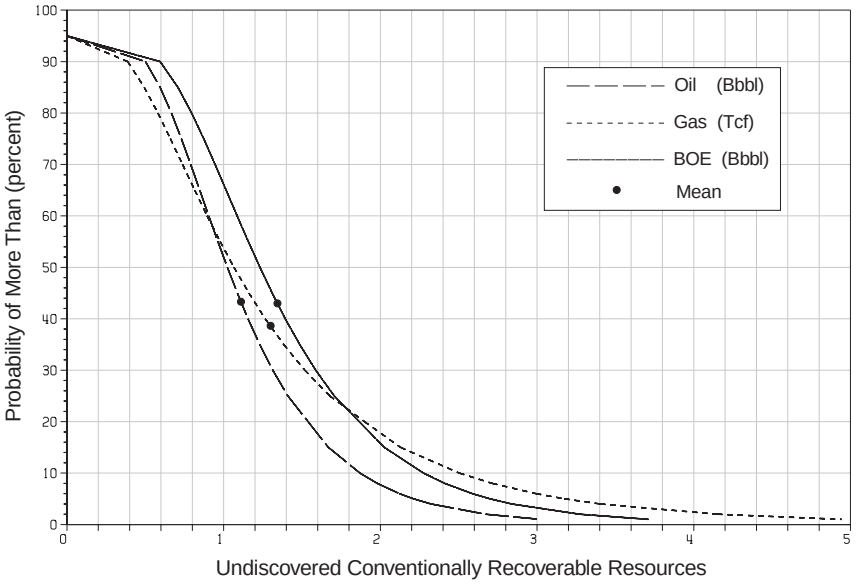

Figure 108. *Cumulative probability plot of estimated undiscovered conventionally recoverable resources of the Oceanside-Capistrano Basin assessment area.*

Table 37. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Oceanside-Capistrano Basin assessment area as of January 1, 1995, by area. All estimates are risked mean values. Some total values may not equal the sum of the component values due to independent rounding.*

Area	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
Onshore		negligible	
State Offshore	0.05	0.06	0.06
Federal Offshore	1.07	1.25	1.29
Total Assessment Area	*1.11*	*1.30*	*1.34*

Undiscovered Economically Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the assessment area that may be economically recoverable under various economic scenarios have been developed using the economic assessment method. Select data used to develop the

Table 38. *Estimates of undiscovered economically recoverable oil and gas resources in the Oceanside-Capistrano Basin assessment area[1] as of January 1, 1995, by economic scenario. All estimates are risked mean values. The $18-per-barrel scenario is based on prices of $18 per bbl of oil and $2.11 per Mcf of gas; the $25-per-barrel scenario is based on prices of $25 per bbl of oil and $2.94 per Mcf of gas; the $50-per-barrel scenario is based on prices of $50 per barrel of oil and $5.87 per Mcf of gas.*

Economic Scenario	Oil (MMbbl)	Gas (Bcf)	BOE (MMbbl)
$18 per barrel	743	869	898
$25 per barrel	882	1,032	1,065
$50 per barrel	1,015	1,188	1,226

[1] Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

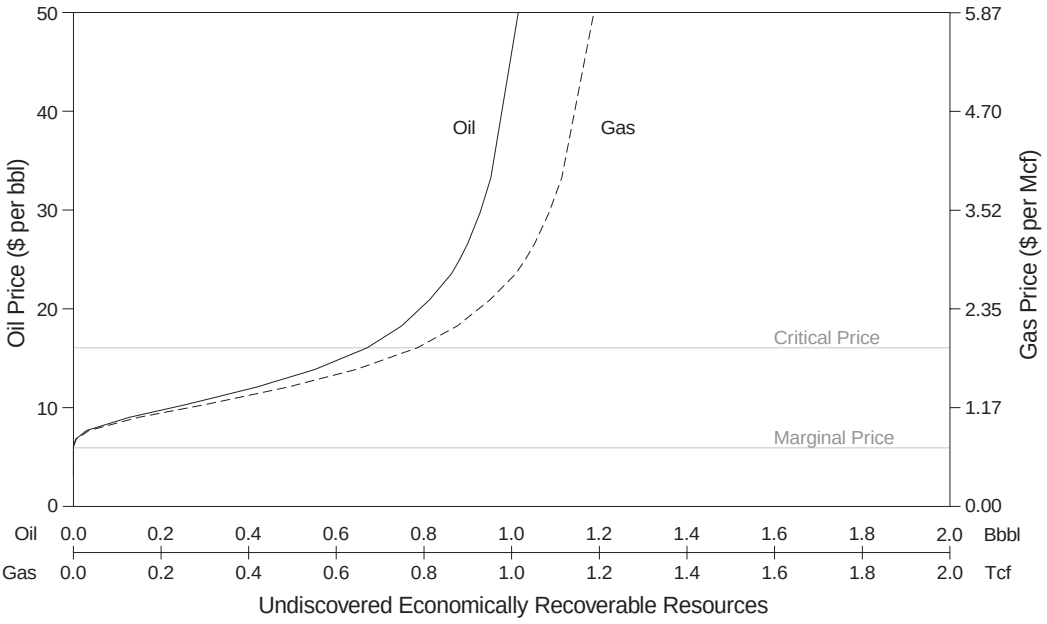

Figure 109. *Price-supply plot of estimated undiscovered economically recoverable resources of the Oceanside-Capistrano Basin assessment area.*

Table 39. *Estimates of the total endowment of oil and gas resources in the Oceanside-Capistrano Basin assessment area. Estimates of discovered resources (including cumulative production and remaining reserves) and undiscovered resources are as of January 1, 1995. Estimates of undiscovered conventionally recoverable resources are risked mean values. Some total values may not equal the sum of the component values due to independent rounding.*

Resource Category	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
Cumulative Production[1]	<0.01	<0.01	<0.01
Remaining Reserves[1]		negligible	
Undiscovered Conventionally Recoverable Resources[1]	1.11	1.30	1.34
Total Resource Endowment[1]	*1.11*	*1.30*	*1.34*

[1] Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

resource estimates are shown in appendix D.

As a result of this assessment, 743 MMbbl of oil and 869 Bcf of associated gas are estimated to be economically recoverable from the Oceanside-Capistrano Basin assessment area under economic conditions existing as of this assessment (i.e., the $18-per-barrel economic scenario) (table 38). Larger volumes of resources are expected to be economically recoverable under increasingly favorable economic conditions (fig. 109).

The majority of undiscovered economically recoverable resources in the assessment area are expected to exist in the Federal and State offshore portions of the area.

Total Resource Endowment

As of this assessment, cumulative production from the onshore portion of the assessment area was 4.6 Mbbl of oil and 11 MMcf of gas; remaining reserves were estimated to be negligible. These discovered resources (all of which are from the Paleogene-Cretaceous Sandstone play) and the aforementioned undiscovered conventionally recoverable resources collectively compose the area's estimated total resource endowment of 1.11 Bbbl of oil and 1.30 Tcf of gas (table 39).

ACKNOWLEDGMENTS

Jim Crouch is acknowledged for sharing his knowledge and insight regarding the Oceanside-Capistrano basin. Larry Beyer was helpful in providing onshore information. Acknowledgment is also due to Bill Kou who performed the seismic interpretive mapping of the offshore part of the basin.

ADDITIONAL REFERENCES

Crouch, 1993
Crouch, Bachman, and Associates, Inc., 1989a
Crouch and Suppe, 1993
Vedder, 1987

UPPER MIOCENE SANDSTONE PLAY

PLAY DEFINITION

The Upper Miocene Sandstone play of the Oceanside-Capistrano Basin assessment area is a conceptual play consisting of accumulations of oil and associated gas in upper Miocene sandstones of the Capistrano Formation. The play exists over most of the offshore portion of the basin (in Federal and State waters) but does not exist onshore (fig. 105). It encompasses an area of about 1,300 square miles; the depth to reservoir rocks in the play ranges from about 1,200 to 5,500 feet below the seafloor.

PETROLEUM GEOLOGIC CHARACTERISTICS

The primary petroleum source rocks for this play are within the Monterey Formation (fig. 106). Mudstones and shales within the lower part of the Capistrano Formation may also have source potential for this play. The type and amount of organic matter within Monterey rocks of the Oceanside-Capistrano basin are largely unknown; however, Monterey rocks in other California coastal basins are rich in organic matter, and similar rocks are presumed to exist in the Oceanside-Capistrano basin. The depth at which thermal maturation may have occurred is also unknown. The Monterey is buried between 5,000 and 8,500 feet (corresponding to temperatures of about 185 to 270 °F, respectively) and, therefore, may have been buried sufficiently to permit petroleum generation.

Potential reservoir rocks in this play are upper Miocene channel and fan turbidite sandstones of the Capistrano Formation (fig. 106); these are probably stratigraphically equivalent to Puente Formation sandstones and lower "Repetto" strata in the Los Angeles basin (see Los Angeles Basin province summary). The Capistrano Formation contains very sand-rich units that are regionally extensive across the offshore part of the Oceanside-Capistrano basin; rocks of this formation are exposed in outcrops onshore from the San Joaquin Hills to south of San Clemente. The Mobil San Clemente corehole penetrated over 3,000 feet of this section, which is sand-rich and of potentially excellent reservoir quality. A number of channel and lobate features (interpreted to be fans) are imaged on offshore seismic-reflection profiles; similar features are exposed in coastal outcrops at Dana Point and San Clemente. Based on basin geometry, these channel and fan deposits were probably depositionally restricted to the basin trough where stacking of multiple reservoir sandstones is likely.

A large number of structural traps—including small to large anticlines and faulted anticlines—within the Capistrano Formation are evident from seismic mapping. The dominant structural trend is along the Newport-Inglewood fault zone. Channel and fan facies outside the Newport-Inglewood structural trend afford excellent opportunities for stratigraphic entrapment.

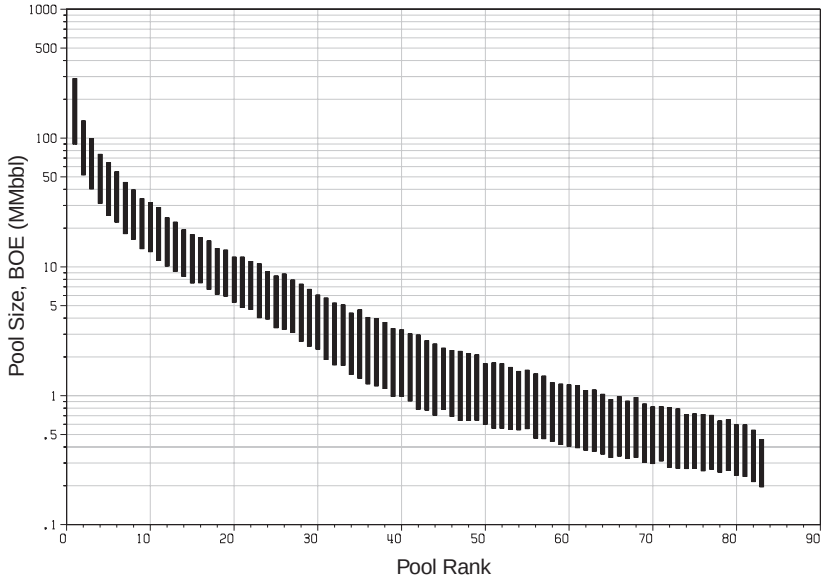

Figure 110. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Upper Miocene Sandstone play, Oceanside-Capistrano Basin assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

EXPLORATION

Both of the coreholes drilled in the offshore part of the basin penetrated rocks of this play. No shows of hydrocarbons were encountered.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method with a combination of play-specific and analog data. Select data used to develop the resource estimates are shown in appendix C.

The size and number of prospects in the play were estimated from seismic mapping. Conservatively modified analog data from Puente producing zones in the Los Angeles basin were used to estimate the net-pay thickness, oil recovery factor, and gas-to-oil ratio for this play.

As a result of this assessment, the play is expected to contain 514 MMbbl of oil and 274 Bcf of associated gas (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 83 pools with sizes ranging from approximately 195 Mbbl to 290 MMbbl of combined oil-equivalent resources (fig. 110). The low, mean, and high estimates of resources in the play are listed in table 36.

The majority of these pools and resources, or approximately 494 MMbbl of oil and 263 Bcf of associated gas, are expected to exist in the Federal offshore portion of the play. The remaining pools and resources, or approximately 20 MMbbl of oil and 11 Bcf of associated gas, are expected to exist in the State offshore portion of the play.

MONTEREY FRACTURED PLAY

PLAY DEFINITION

The Monterey Fractured play of the Oceanside-Capistrano Basin assessment area is a conceptual play consisting of accumulations of oil and associated gas in middle to upper Miocene fractured rocks of the Monterey Formation. The play exists over most of the offshore portion of the basin (in Federal and State waters) but does not exist onshore (fig. 105). It encompasses an area of about 1,000 square miles; the depth to reservoir rocks in the play ranges from about 3,400 to 8,500 feet below the seafloor.

PETROLEUM GEOLOGIC CHARACTERISTICS

The Monterey Formation is considered to be both source rock and reservoir rock for this play (fig. 106) by analogy with Monterey rocks in the offshore Santa Barbara-Ventura and Santa Maria basins and the onshore San Joaquin basin. The type and amount of organic matter within Monterey rocks of the Oceanside-Capistrano basin are largely unknown; however, Monterey rocks in other California coastal basins are rich in organic matter, and similar rocks are presumed to exist in the Oceanside-Capistrano basin. The depth at which thermal maturation may

have occurred is also unknown. The Monterey is buried between 5,000 and 8,500 feet (corresponding to temperatures of about 185 to 270 °F, respectively) and, therefore, may have been buried sufficiently to permit petroleum generation.

Potential reservoir rocks in this play include fractured shale, dolomitic limestone, sandstone, siltstone, and chert of the Monterey Formation (fig. 106). Monterey rocks in the offshore Oceanside-Capistrano basin have been penetrated by one corehole; the corehole and offshore seismic data suggest that the Monterey section is more than 1,500 feet thick in most of the play area. Onshore, Monterey strata outcrop along the coast from Newport Beach to Oceanside where they are described as calcareous, siliceous, and phosphatic (Crouch, 1993). The outcrop data indicate that Monterey rocks are much dirtier (clays and mudstones) than in the offshore Santa Barbara-Ventura and Santa Maria basins; therefore, porosity and permeability of Monterey reservoir rocks may be diminished in this basin.

The Newport-Inglewood fault zone has created a number of small to large anticlines, fault traps, and subthrust traps within the basin. The potential for stratigraphic entrapment in this play is considered to be minor.

EXPLORATION

One of the coreholes (Mobil San Clemente) drilled in the offshore part of the basin penetrated rocks of the Monterey Formation. No shows of hydrocarbons were encountered.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method with a combination of play-specific and analog data. Select data used to develop the resource estimates are shown in appendix C.

The volume and number of prospects in the play were estimated from seismic mapping. Conservatively modified analog data from Monterey producing zones in the offshore Santa Barbara-Ventura and Santa Maria basins were used to estimate the oil recovery factor and gas-to-oil ratio for this play.

As a result of this assessment, the play is estimated to contain 387 MMbbl of oil and 452 Bcf of associated gas (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 76 pools with sizes ranging from approximately 40 Mbbl to 290 MMbbl of combined oil-equivalent resources (fig. 111). The low, mean, and high estimates of resources in the play are listed in table 36.

The majority of these pools and resources, or approximately 371 MMbbl of oil and 435 Bcf of associated gas, are expected to exist in the Federal offshore portion of the play. The remaining pools and resources, or approximately 16 MMbbl of oil and 17 Bcf of associated gas, are expected to exist in the State offshore portion of the play.

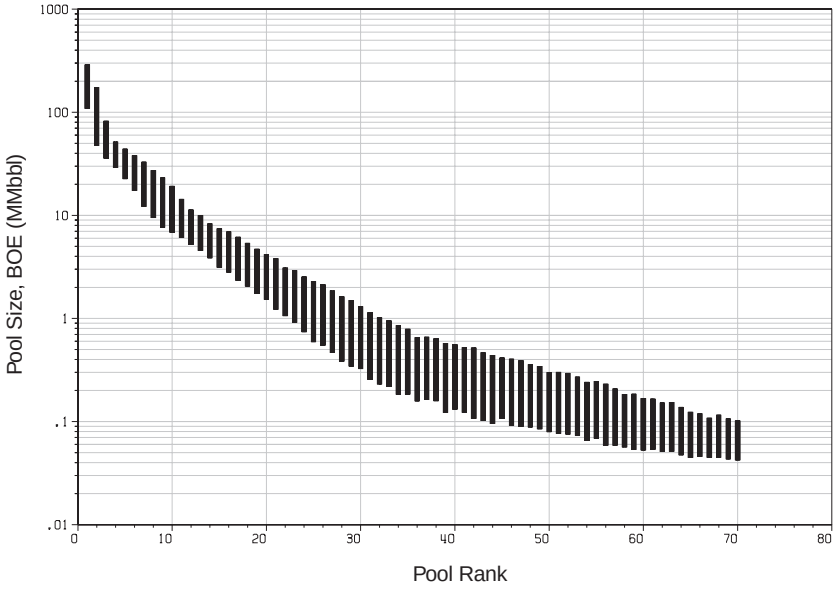

Figure 111. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Monterey Fractured play, Oceanside-Capistrano Basin assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

LOWER MIOCENE SANDSTONE PLAY

PLAY DEFINITION

The Lower Miocene Sandstone play of the Oceanside-Capistrano Basin assessment area is a conceptual play consisting of accumulations of oil and associated gas in lower to middle Miocene clastic rocks of the San Onofre Breccia, Topanga Formation, and Vaqueros Formation. The play exists offshore in the eastern two-thirds of the basin (in Federal and State waters) but does not exist onshore (fig. 105). It encompasses an area of about 700 square miles; the depth to reservoir rocks in the play ranges from about 5,200 to 9,800 feet below the seafloor.

PETROLEUM GEOLOGIC CHARACTERISTICS

Potential source rocks for this play are the Monterey Formation, lower Miocene shales in the Vaqueros Formation, and Eocene shales in the Santiago Formation(?) (fig. 106). The type and amount of organic matter within Monterey rocks of the Oceanside-Capistrano basin are largely unknown; however, Monterey rocks in other California coastal basins are rich in organic matter, and similar rocks are presumed to exist in the Oceanside-Capistrano basin. The Monterey is buried between 5,000 and 8,500 feet (corresponding to temperatures of about 185 to 270 °F, respectively) and, therefore, may have been buried sufficiently to permit petroleum generation.

Potential reservoir rocks in this play include sandstones, siltstones, and conglomerates of the Vaqueros and Topanga Formations and the San Onofre Breccia (fig. 106). Based on onshore wells and outcrops, the Vaqueros Formation consists of shallow-marine sandstone, siltstone, and conglomerate; the Topanga Formation consists of deep-marine turbidite sandstone, siltstone, conglomerate, breccia, and shale; and the San Onofre Breccia consists of conglomeratic breccia, conglomerate, and sandstones. The San Onofre Breccia exists in extremely lenticular bodies in coastal outcrops with coarse sandtones that were deposited in submarine fan channels. The medium- to coarse-grained sandstones within the San Onofre Breccia could be excellent reservoir rocks. Porosity and permeability should be preserved within these rocks due to the moderate depths of burial.

A number of small to large anticlines, fault traps, and subthrust traps within this play are evident from seismic mapping; most of these features exist along the Newport-Inglewood fault zone. Some potential for stratigraphic entrapment exists where strata pinch out along the western margin of the play.

EXPLORATION

The San Onofre Breccia was penetrated by one of the coreholes (Mobil San Clemente) drilled in the offshore part of the basin; however, no shows of hydrocarbons were encountered. The Vaqueros and Topanga Formations were not penetrated by either of the coreholes. Vaqueros strata are evident on seismic-reflection profiles and pinch out westerly across the basin.

The formations included in this play are productive in several areas of the onshore and offshore Los Angeles and Santa Barbara-Ventura basins. However, no hydrocarbons have been discovered in these formations in the onshore part of the Oceanside-Capistrano basin.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method with a combination of play-specific and analog data. Select data used to develop the resource estimates are shown in appendix C.

The volume and number of prospects in the play were estimated from seismic mapping. Analog data from Vaqueros, Sespe, and Alegria producing zones in the offshore Santa Barbara-Ventura basin were used to estimate the net-pay thickness, oil recovery factor, and gas-to-oil ratio for this play.

As a result of this assessment, the play is estimated to contain 208 MMbbl of oil and 568 Bcf of associated gas (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 74 pools with sizes ranging from approximately 60 Mbbl to 310 MMbbl of combined oil-equivalent resources (fig. 112). The low, mean, and high estimates of resources in the play are listed in table 36.

The majority of these pools and resources, or approximately 200 MMbbl of oil and 546 Bcf of associated gas, are expected to exist in the Federal offshore portion of the play. The remaining pools and resources, or approximately 8 MMbbl of oil and 22 Bcf of associated gas, are expected to exist in the State offshore portion of the play.

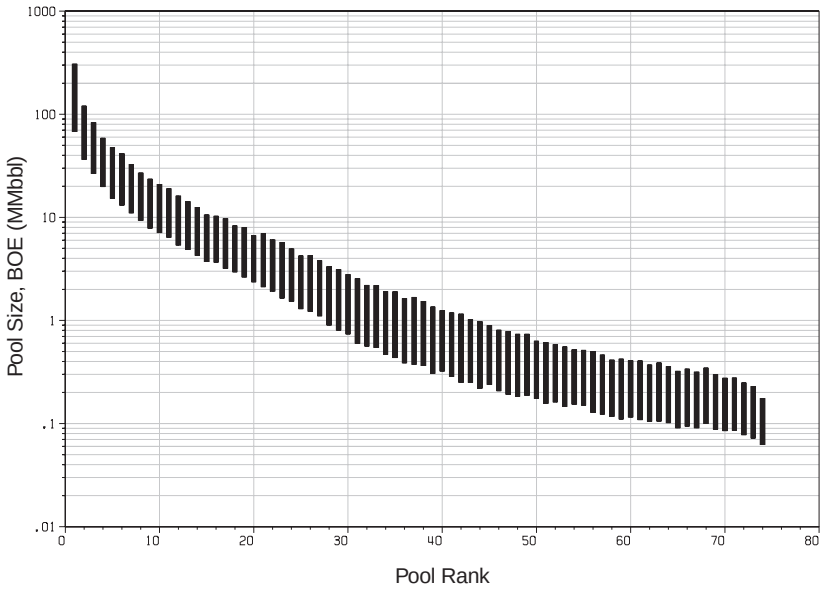

Figure 112. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Lower Miocene Sandstone play, Oceanside-Capistrano Basin assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

PALEOGENE-CRETACEOUS SANDSTONE PLAY

PLAY DEFINITION

The Paleogene-Cretaceous Sandstone play of the Oceanside-Capistrano Basin assessment area is an established play consisting of accumulations of oil and associated gas in Upper Cretaceous and Paleogene sandstones. The play exists onshore and offshore (in Federal and State waters) along the eastern margin of the basin (fig. 105). It encompasses an area of about 400 square miles. The depth to reservoir rocks in the play onshore ranges from about 2,000 to 5,000 feet below the surface; offshore, the depth to reservoir rocks ranges from about 8,000 to 10,500 feet below the seafloor.

Offshore strata included in this play are presumably equivalent to onshore strata of the Upper Cretaceous Williams Formation, Paleocene Silverado Formation, Eocene Santiago Formation, and Oligocene Sespe Formation (fig. 106). These strata outcrop onshore from San Clemente to La Jolla and have been penetrated by numerous exploratory wells in the Capistrano syncline. Oligocene strata are predicted to exist offshore based on extrapolation of onshore outcrop and well data southward using seismic-reflection profiles. The Cretaceous and Paleogene strata are depositionally restricted to the eastern area of the basin where they extend slightly west of the Newport-Inglewood fault zone.

PETROLEUM GEOLOGIC CHARACTERISTICS

Potential petroleum source rocks for this play are Upper Cretaceous and Paleogene shales (fig. 106). Although the thermal history of these rocks should be sufficient to generate oil and gas, the volume of source rock may be lacking (the type and amount of organic matter are unknown); as a result, the amount of oil and gas generated from these rocks is expected to be small.

Potential reservoir rocks in this play include sandstones and conglomerates of the Williams, Silverado, Santiago, and Sespe Formations (fig. 106). Based on onshore wells and outcrops, the Williams Formation consists primarily of thin shallow-marine sandstone; the Silverado Formation consists of nonmarine sandstone and conglomerate; the Santiago Formation consists of marine sandstone, conglomerate, and mudstone; and the Sespe Formation consists of nonmarine sandstone, conglomerate, and mudstone. Sandstones of these units should have fair to good porosity and permeability, although the reservoirs are expected to be thin.

The dominant trap types in this play are small anticlinal folds and fault traps. Although seismic profiles have been used to determine the offshore extent of the play, the quality of the profiles in this

deep section is very poor; therefore, the profiles are inconclusive for mapping structures and trends.

EXPLORATION AND DISCOVERY STATUS

Two fields have been discovered in the onshore part of this play. Collectively, the San Clemente and Cristianitos Creek fields produced a very small quantity (less than 5 Mbbl) of high-gravity (45 to 54 °API) oil and gas from the Upper Cretaceous Williams Formation in the late 1950's. Both fields were considered to be subcommercial and have been abandoned.

Neither of the coreholes drilled in the offshore part of the basin penetrated rocks of this play.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method with a combination of play-specific and analog data. Select data used to develop the resource estimates are shown in appendix C.

The volume and number of prospects in the play were estimated from seismic mapping. Analog data from Eocene and Oligocene producing zones in the offshore Santa Barbara-Ventura basin and the onshore Los Angeles and San Joaquin basins were used to estimate the net-pay thickness, oil recovery factor, and gas-to-oil ratio for this play.

As a result of this assessment, the play is estimated to contain 3 MMbbl of oil and 8 Bcf of associated gas (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 27 pools with sizes ranging from approximately 40 Mbbl to 8 MMbbl of combined oil-equivalent resources (fig. 113). The low, mean, and high estimates of resources in the play are listed in table 36.

The majority of these pools and resources, or approximately 3 MMbbl of oil and 7 Bcf of associated gas, are expected to exist in the State offshore portion of the play. The remaining pools and resources, which are negligible, are expected to exist in the onshore and Federal offshore portions of the play.

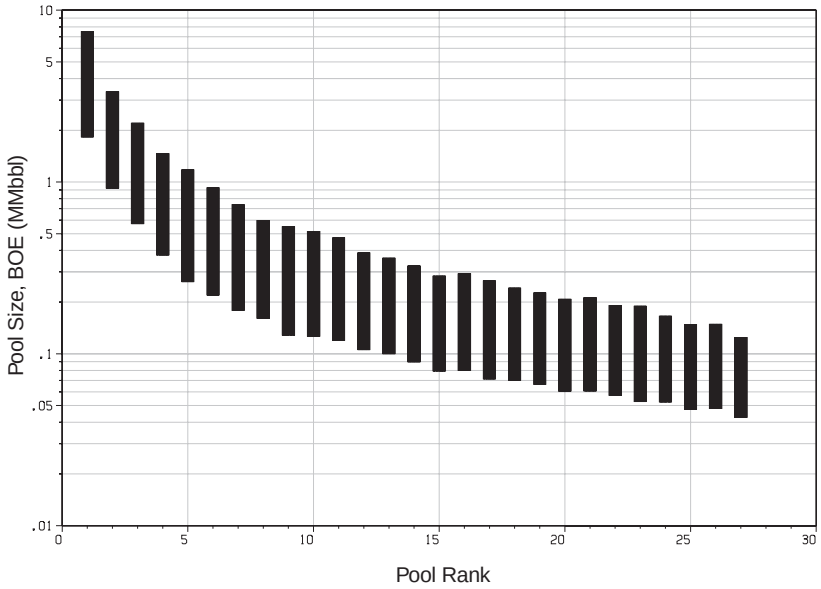

Figure 113. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Paleogene-Cretaceous Sandstone play, Oceanside-Capistrano Basin assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*